Proceedings of the International Association for Shell and Spatial Structures (IASS)
Symposium 2015, Amsterdam
Future Visions
17 - 20 August 2015, Amsterdam, The Netherlands

Interactive bi-directional BIM model and application linking

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Abstract

Despite an accelerated growth in BIM adoption and advanced digital design tools for construction projects, throughout the building project lifecycle, there still is no "single source of truth", as project information is spread over different models and files. Together they form a federated, digital representation of the project, with all embedded knowledge and information. Alas, we still rely on interoperability techniques to exchange files and models between systems, which implies, by definition, a certain loss of information and which also hinders automation of processes.
This article presents a technological approach for cross-application, cross-platform and cross-device communication of project information, to automate not only design but also reporting and feedback workflows. This is illustrated with considerations from a recent use case and with an outlook to key implementations for future workflows. A centralized web dashboard makes the project workflows and information accessible from any device using only a browser.
We are convinced that this technique for setting up live connections between applications, databases and management dashboards will facilitate the long-term migration towards BIM Maturity Level 3.

Keywords: Building Information Modeling, OpenBIM, project management, web dashboard, middleware, web services, interoperability, automation, BIM Level 3.

1. Introduction

The last few years, we have seen an accelerated growth in BIM adoption for construction projects (Gu and London [8], Eadie et al. [5], Malleson et al. [9], Waterhouse et al. [19]), although this usually occurs with more forward thinking offices and companies. BIM has been accepted and sometimes even specified in projects. Building practice but also construction education is taking the necessary steps to train (future) building professionals (Morton [10], Platts [13]), to provide best practices and develop innovative solutions for BIM-based workflows.

Most architectural and engineering offices apply a wide variety of software systems, ranging from traditional CAD drafting and basic 3D modelling up to advanced simulation. Their hybrid workflow is usually not fully organized and might occur in an ad-hoc fashion, intermixed with analog drafting and model making.
In the context of improving and optimizing current design workflows, many innovative design offices apply advanced digital modelling and analysis approaches in their projects and set up workflows where the design process itself is supported and improved with digital tools.
There is a growing awareness of the importance of a holistic lifecycle approach, both in the process and the project (Basbagill [2]). The process is supported with the creation and elaboration of models and their embedded information, whereas the project requires a better informed design, by taking many dimensions into account, such as the assessment of the environmental impact of materials, but also energy and functional performance (Bahar et al. [1], O'Donnell et al [11]) or code compliance assessment (Tan et al. [16]).

1.1. Problem Statement

This paper focuses on limitations encountered in current digital design workflows, and how we can improve the process with new, innovative technology.
We define a design model as a virtual, digital repository of design information, embedding not only technical aspects but also design intent and project knowledge. However, with the current hybrid approaches, this occurs over a wide range of software systems. As a result, our digital design knowledge is spread over multiple partial representations and models, in a variety of files and databases, which form a federated, digital representation of the project, with all embedded knowledge and information.
As a result, since there is no "single source of truth" comprising all project information, we still rely on interoperability techniques to exchange files and models between systems, which implies, by definition, a certain loss of information and which also hinders automation of processes. This is often related to file-based approaches, as opposed to data-centric approaches, using databases and integrated processes (Smith [14]). There is often more attention to the "M" rather than the "I" in BIM. Pauwels ([12]) suggests evolving to an *Architectural Information Model* with the application of *Semantic Web* technologies and ontologies.
There is a strong reliance on manual, labor intensive, file based information exchange in projects, when models are exported in other formats, to be imported in other, disconnected systems. This presents a serious hindrance to process automation and as such, limits the amount of design iterations that occur in a project.

2. BIM Project Management in the cloud

A part of the solution to improve collaboration in BIM-based workflows is through online platforms for BIM Model sharing and communication. We first look at some existing platforms and evaluate their possibilities, but also their limitations.
There are many collaboration platforms, such as *Autodesk Buzzsaw*, *A360, BIM360 Glue*, *Nemetschek Allplan BIM+*, *Trimble Connect*, *Graphisoft BIM Cloud* or Open Source initiatives, such as *BIMserver* using *BIMvie.ws* and *BIMsurfer*.

With *A360*, but also with platforms such as *BIM+* and *Trimble Connect*, shown in the following figure, uploaded 3D models can be directly visualized inside the browser, with nothing to install.

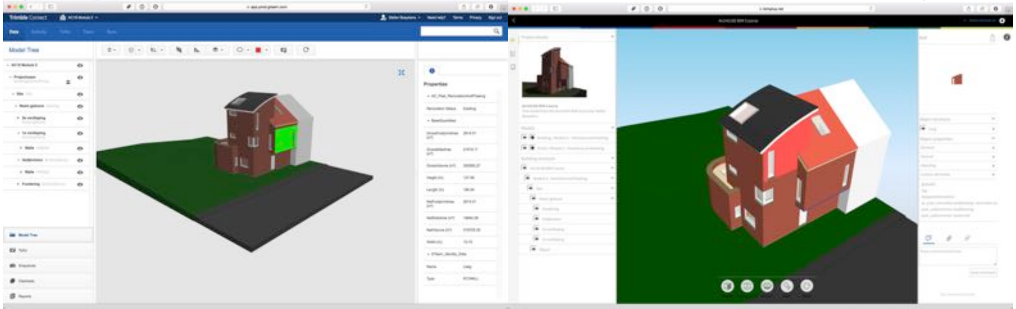

Figure 1: Trimble Connect (left) and BIM+ (right) displaying the same IFC model

Some of the platforms are primarily advanced file sharing systems (e.g. *Autodesk A360*, *Bricsys Chapoo*, *Autodesk Buzzsaw*), where you can upload and manage model files in the cloud, with support for teams, projects and with an integrated viewer of some of the file formats. Usually, neutral formats are supported, such as IFC, DWG or PDF. With platforms from software vendors sometimes native files are supported as well, e.g. RVT files for Autodesk platforms.
Other platforms are BIM-specific, e.g. with IFC at the core of the model storage, such as *BIMserver* or *BIM+* and with viewer access to element information. Platforms such as *BIM360 Glue* and *BIMServer* support the aggregation of aspect or discipline models, in line with current best practices for collaborative BIM workflows (van Berlo et al. [17]), but this is often ignored in generic document sharing platforms, where you can only visualize a single model at once.
The example of *Graphisoft BIM Cloud* is a-typical, as it supports only *ArchiCAD*, but it enables concurrent, collaborative design, directly from the modeling software.
In many cases, these platforms provide an *Application Programming Interface* or *API* for the data back-end and/or the 3D model viewer component. With a back-end API, you can build a custom system around this storage and utilize user and project management. This also supports model conversion from uploaded files. With a viewer API, you can embed an interactive viewer widget into your own front-end, provided you can feed it with the necessary model geometry and data.

However, we encountered several workflow limitations in such platforms:

- Most systems are file-based and the only way to push data into the back-end is by uploading model files, although the API can be used for automation.
- The data back-end is usually the end-point in the process, with at most the possibility to download uploaded files again.
- Information is read-only, with the only user interaction through commenting, e.g. using the *BIM Collaboration Format* (BCF) Standard.
- All viewers offer interactive orbiting, zooming and panning, but it is not always possible to control selection, highlighting, visibility or color from the API.

- Moreover, many viewers are inherently tied to the back-end and pose compatibility limitations (e.g. BIM 360 Glue only supports Windows or iPad).

The next table summarizes the comparison of BIM Collaboration Platforms, looking at main features, availability of an API and control over model and/or viewer.

Feature	Autodesk A360	Autodesk BIM360	Autodesk Buzzsaw	Allplan BIM+	Trimble Connect	Bricsys Chapoo	Graphisoft BIMCloud	BIMserver
Storage/API	X/X	X/X	X/-	X/X	X/X	X/-	X/-	X/X
Viewer/API	X/X	X/-	X/-	X/X	X/X	2D/-	-/-	X/X
Coordination	-	X	-	(soon)	-	-	X	X
Native Files	X	X	X	-	-	X	X	-
IFC	X	X	X	X	X	X	-	X
Edit Model	-	-	-	API	-	-	X	X

Figure 2: BIM Platforms Comparison Table

Based on this analysis, we are now developing a middleware solution focusing on bridging some of the existing gaps and sticking to some specific advantages:

- Staying independent from one particular software vendor;
- Maintaining the potential to integrate with different software platforms at once;
- Focusing on workflow integration rather than end user products.

While we don't cover all features of existing platforms, we are flexible to mix and match between existing and custom components for interoperability and exchange, but also to organize different displays and visualizations. This allows building upon existing solutions where relevant, but also to set up a custom system from scratch.
As an AEC innovation and development company, D-Studio is more focusing on enabling workflows and custom solutions, rather than providing an out-of-the-box end user product or system.

3. The xD Engine Middleware & BIM Dashboard

The rest of the article presents an approach for cross-application, cross-platform and cross-device communication of information, to automate not only design but also reporting and analysis workflows. This is inspired by our current solutions, but also on demands from clients and project owners for future, innovative workflows.
Whereas the middleware technology is the enabler for these workflows, the end user (owner, project manager, contractor, designer) will mostly benefit from a centralized BIM dashboard, accessible online from any device using only a browser. This dashboard integrates models, databases and analysis results from different applications and connected systems.
E.g. a project manager will use the dashboard to request the project status and receives feedback using various embedded widgets, including a real-time 3D viewer but also interactive charting and diagramming displays. The dashboard has a bi-directional live link with the models, allowing or analysis results from e.g. requirements checking to be pushed back into the model, if needed. There is a complete audit trail of information flows and integrated visual feedback, such as element highlighting across different systems.

The solution developed by D-Studio exists of two main technologies: the middleware and the BIM dashboard.

3.1. xD Engine Middleware

The *xD Engine Middleware* is invisible to the user, but sets up a communication workflow between applications, with little inherent limitations. A small communication plug-in is hosted inside existing applications, such as *Revit* or *ArchiCAD*, but also *SketchUp* and *Excel*, with other systems such as *Navisworks* in preparation. Instead of enforcing specific applications to the user, the middleware leverages common applications and adds a communication layer through their API. To prevent slow and often manual file-exchange, the applications will talk directly to each other and file import or export is automated in the back-end.
This basically follows a client-server scheme, with an unlimited amount of clients talking to servers, in a layered approach. When a server module is available, either on a local machine, in the local network or online, clients can register themselves and start entering communication channels, by sending and listening to events. As such, messages between clients can be sent locally on a machine, to other machines in the same network or to any other online client, worldwide.

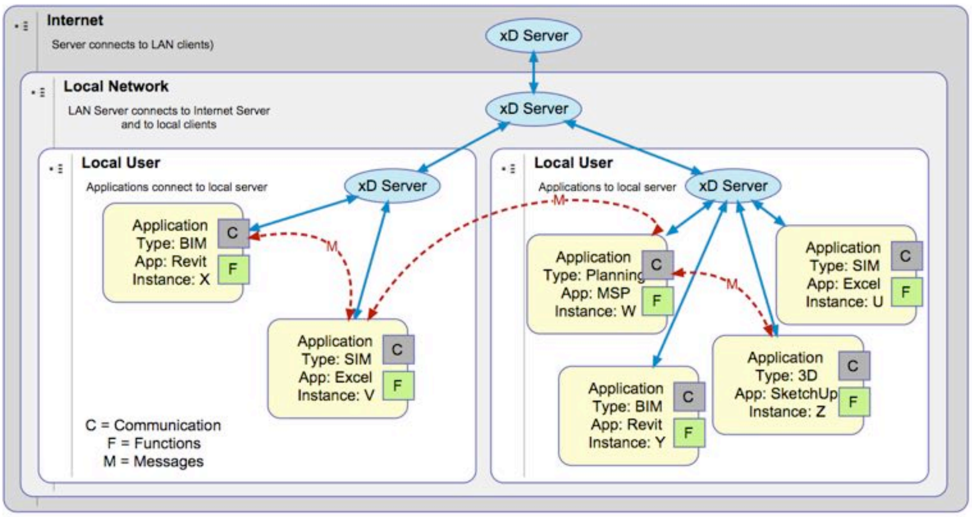

Figure 3: xD Engine Middleware Scheme

E.g. a cost application implemented as an *MS Excel* Spreadsheet will receive model information from a BIM authoring application such as *Revit*. They can run on different machines and in different locations. By using *websockets*, the *xD Engine Middleware* supports immediate, bi-directional communication. This allows the clients to send events to all other clients, but also be pushed by events from other clients.
With this concept, BIM model and document storage is also implemented as another client, which connects to the communication servers and which can present itself as being available to other clients in the connected network.

We foresee both a direct communication to connected authoring systems, e.g. allowing the BIM software to load a native model, manipulate it and send back model information, but also a cached model information storage, for situations when the connected client is not available or offline.

3.2. Developing a BIM Dashboard

The second technology is the BIM Dashboard. This is implemented as a web application, running inside a browser and accessible to end-users. The dashboard has several widgets to visualize project information, but also to interact with the information.

The interactive 3D model viewer will not only display model geometry, but can be used to visualize additional layers of information, using highlighting, color coding and selective hiding/showing of model elements. In addition to 3D geometry using lightweight meshes derived from IFC models by the back-end, 2D or 3D curves and annotation can be displayed for GIS data or model feedback.
As a web application, the client machine is running the display and reacting to the user, profiting from *GPU* hardware acceleration, whereas the model pre-processing and storage occurs on the server.
There are also different other widgets in development: a planning widget (*Gantt* chart), a tree-widget providing a hierarchic display of model data such as spatial relations or model decomposition and a grid or tabular widget for reporting in a spreadsheet-like format.
All widgets are interactive and react on selections, filters and highlights. E.g. when you select a row in the spreadsheet, the corresponding element can be highlighted in the model viewer and in the tree-widget at the same time.
In addition, certain attributes can be edited, although this is (deliberately) limited to those attributes, which have no influence on the model geometry, even though this is technically feasible by the engine. In that case, however, actual geometry changes would have to be pushed and pre-processed again and requires a more refined definition of user roles and permissions.

4. Putting the xD Engine and BIM Dashboard to work: Use Cases

D-Studio is currently evaluating and testing this platform in the context of an actual, large construction project, to assess its robustness and scalability and to further develop the required components.
The *European Investment Bank* (EIB) is preparing a new office building at their Luxemburg site, directly connected to their current main office. The design is the result of an architectural competition and consists of a long volume with a tower. The main entrance is accented with a three-story cantilever volume. Due to confidentiality limitations, we cannot directly show project details and images, so the rest of the use case will focus on the process and the application of the BIM Dashboard.
The project owner stipulated the use of BIM from the Preliminary Design stage up to the Operation and Maintenance Phase, although the architectural contest did not involve the use of BIM. Currently, BIM is increasingly being used after initial design, but not often into operation (Eadie et al. [5]), although we see an increased attention to standards such as *COBie* (East and Carrasquillo-Mangual [6], East [7]).

D-Studio is involved as BIM Specialist to assist and organize the BIM workflow on the side of the project management team, which evaluates the work of the design team.

The project adheres conceptually to the *PAS 1192:2* (BIM Task Group [3]) for process organization. There is a *Common Document Environment* (CDE) to be used by the design team for project coordination, in particular the *Autodesk Buzzsaw* platform. We focus in this article on the BIM part of the workflow. The design team uses a combination of *Autodesk Revit, Civil3D* and *Navisworks* for model authoring. Project planning will be integrated with the *Primavera P6* planning system, leading to a 4D model (planning linked to the 3D BIM Model). Costing will be estimated using *Exactal CostX*, leading to a 5D model (costing linked to the 3D BIM model). There is also the intention to check the model against program & system requirements (6D), where our Revit-*Relatics* integration could be applied.
Although BIM is not required in the current legal context of Luxembourg, the project owners want to push the use of BIM into operation and, as documented in the project BIM Strategy Guide, will follow the recommendations from *PAS 1192:3* (BIM Task Group [4]).

Within this project, a first operational version of the BIM Dashboard is being implemented. While the first phase of the implementation is still file-based, the next phase will further integrate the *xD Engine Middleware*, to provide a more flexible and interactive communication between the BIM Dashboard and the different authoring tools. This uses a combination of pre-collected model information, stored in the back-end database, but also with references to the source models, which can be opened in their native environment, allowing live interrogation of the model.
The 3D Model viewer widget allows a direct and interactive visualization of the design. Using *WebGL* we get a GPU-accelerated display, without plug-ins. This ensures that it is supported on all current web browsers and on all current operating systems. Mobile applications can reuse the same widgets. Through the prototyping phase we studied existing viewers, but also set up a custom widget, using the *Three.js* JavaScript library, with full control over functionality. In a full dashboard several widgets can be combined, allowing better integration with existing client systems and current workflows.

The following example illustrates a more conceptual representation of the design, where only *IfcSpaces* (*Rooms* in *Revit*, *Zones* in *ArchiCAD*) are displayed and colored according to their assigned *Space Category*. Custom coloring permits the user to get more insight into the project and proves to be underdeveloped in the existing BIM viewer widgets available.

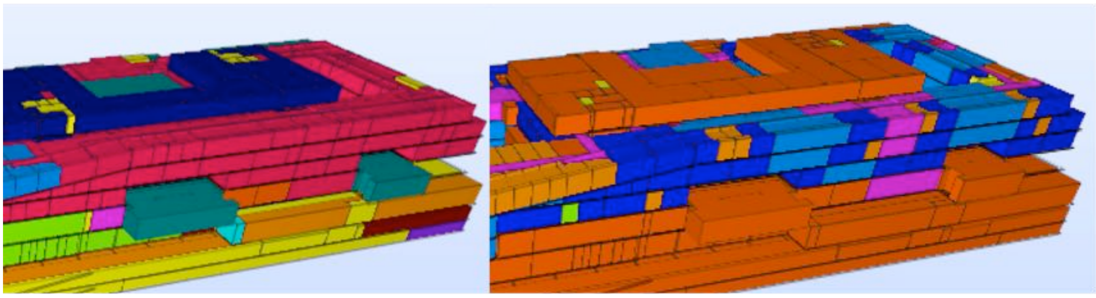

Figure 4: Conceptual Model Display, based on Space Categories

At the same time, other widgets can display tabular information, such as a color legend to clarify the conceptual display and related quantities or counts, as illustrated in the following table fragment.

Category	Count	Color
Circulation	464	
Entrance	24	
Retail services	8	
Sports infrastructures	22	
Car park	46	
Office spaces	842	

Figure 5: Fragment of a table widget for Space Categories

Selecting rows in the legend can adapt the display, e.g. hiding other categories or displaying them transparently. It is necessary to provide combinations of visualizations that are related and thus provide better insight to the user, which is not the case when diagrams or displays are used individually. It is also important to apply charts that present the relation between parameters, rather than individual magnitudes, in line with recommendations from Tableau ([15]).
It is best to understand a BIM Dashboard in the context of *Business Intelligence* applications. Through the concurrent visualization of multiple aspects in different graphs or diagrams, but linked together in an interactive format, users can study and explore information and drill down to details or zoom out to get a broad overview. While BIM modelers and building professionals can inspect the model directly, some important project stakeholders don't have this experience. The dashboard is an enabler and facilitator for them to get a grip on project information, but presented in a user-friendly and less intrusive way than by directly using specialized BIM authoring software.

D-Studio also leverages the experience from the *4D VirtualBuilder* product, displayed in the following figure, where planning information is visualized in the context of the 3D model in *SketchUp* and juxtaposed with a *Gantt* chart widget and an element table. Selecting an element in the table highlights it in the model as well and scrolling through the timeline toggles element visibilities and uses color to display their status.

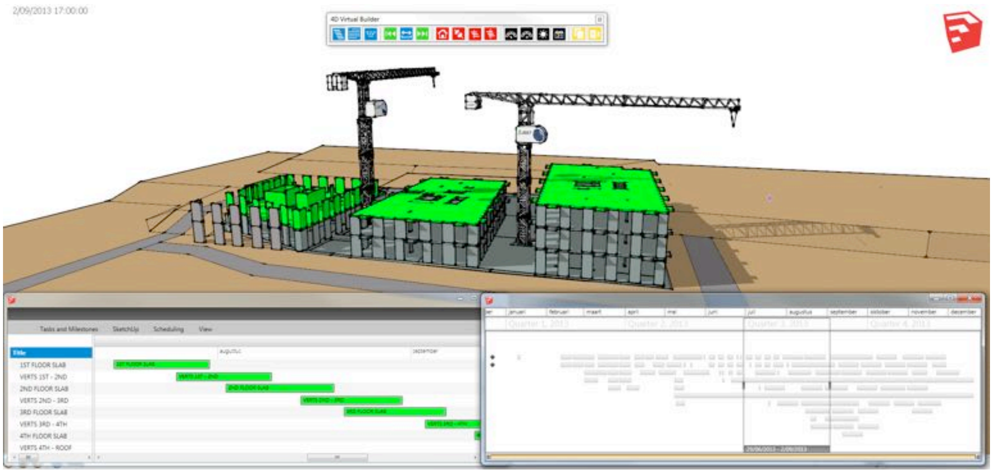

Figure 6: 4D Virtual Builder Example Displays (D-Studio)

Whereas *4D Virtual Builder* has been developed as a Windows desktop application, extending SketchUp with additional planning views, the BIM Dashboard will integrate similar components directly in a web browser with nothing to install for the user, but linked to the model data, via the xD Engine backend.

It is envisaged that many of the custom applications developed by D-Studio will be ported to xD Engine Middleware and made accessible via the BIM Dashboard.

5. Evaluation & Future Outlook

Whereas the construction sector in the UK and other BIM-minded regions is aiming towards *BIM Maturity Level 2* in the short term, it is necessary to prepare the next phase: *BIM Maturity Level 3*, with connected services and open integrated models. We believe that a BIM Dashboard built on top of a back-end with the ability to communicate to various connected applications and data servers will facilitate this evolution.

In this article we looked at the different components to organize such platform and also how it is being tested in an actual construction project, rather than in an idealized, theoretical setting. We also explicitly leverage existing solutions, such as BIM Modelling tools and Open Standards, and focus on the technologies to support connected, interoperable workflows, with automation in mind.

Of course, the full operational platform is not finished and not all parts have been implemented, but in a modular approach, we are already seeing the benefits and the potential to support construction projects with this approach.

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